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BIOLOGICAL BULLETIN

PALM AND SOLE STUDIES.

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(*Continued from page 172.*)

V. Friction-Skin Correspondence in Pygopagi.

A long series of studies of the palm and sole markings in human twins, both *duplicate and fraternal*,[1] has established two principles for twins of the true duplicate type (monochorial, monosexual, striking facial resemblance, etc.), viz: (1) that the corresponding palms and soles in the two individuals are strikingly alike in friction-ridge configuration, even duplicating singular and unusual features, and (2) that the correspondence in the two sides of the same individual is far greater than is usually the case, so that the four hands involved, or the four feet, present so many copies of practically one picture. To these may be added a third condition, not absolutely constant, but frequently noted; a reversal of the pattern of the index figures in the two individuals, affecting either the two right hands or the two left hands, or occasionally both sets.

In this connection it is a matter of great importance to ascertain the condition of the friction ridges in "conjoined" twins, that is, in twins which have never completely separated, but remain throughout life united by certain common parts (i. e., double monsters). The numerous specimens of this sort found in teratological museums have yielded some results, which seem to accord with the findings in separate duplicate twins, but such objects are unsatisfactory to study since they are mostly embryonic, or newborn, and the ridges in consequence are very soft and indistinct, while the fluid in which they are preserved renders a print difficult or impossible.

Recently, however, I have had the opportunity of making

[1] Wilder, 1902, 1904, 1911.

careful observations of a pair of living conjoined twins, who were born in May, 1912, and are consequently in their fourth year at the present writing. These twins, which I studied the first time a day or two after birth, are typical pygopagi, of the well-known but rare type represented by Rosa–Josepha Blazek, and Millie–Christine;[1] are united in the sacro-iliac region, but placed somewhat obliquely, so that, instead of looking in directly opposite directions, they are rotated about 45° towards the same side.

It thus happens that, while lying or sitting they present to the observer what would be called a front and a back side, considering the entire double monster as a unit, so that when the observer is stationed upon the "front" side the two faces are turned 45°

[1] Double twins of the pygopagous type are extremely rare. Baudouin, in 1902, was able to cite but eight authentic cases that have lived, known to the medical profession, and these span an interval of eight hundred years. These are as follows:

1. The "Biddenden Maids"; Biddenden, Co. Kent, England, b. 1100. d. 1134.
2. Case cited by Lycosthenes, writing in 1665. These were girls, b. in Verona, Italy, in 1475.
3. The Hungarian Sisters, Helena–Judith; b. near Komorn, Hungary, 1701, d. 1723.
4. Case cited by Wolff; observed in Russia in 1778, lived but two months.
5. Millie–Christine, negresses; b. in South Carolina, exhibited at Edinburgh in 1856, and later on in the United States. [They died about 1912.]
6. Case of Joly and Peyrat, Jeanne–Marguerite Bombail; b. 1874, at Mazéres, Dept. Ariége, France. Died 24 hours after birth.
7. Case of Pilat, 1879. Born prematurely and one died during delivery.
8. The Bohemian Sisters, Rosa–Josepha Blazek; b. Jan. 20, 1878, and still living (1915). One of these is reported to have borne a normal child. These sisters are well educated, speak several languages with fluency, and have been extensively exhibited.

To this list must now be added (9) the "Samar Twins" Lucio–Simplicio, two boys from the island of Samar, in the Philippines, also (10) the subjects of this paper. The boys are about six years of age at this writing, the girls three and a half. Both sets were born since the above compilation was made.

That similar cases have occurred among primitive peoples, and in the past, is evidenced by the occurrence of folk-lore tales, describing such double twins with some degree of care, and rendering it probable that they were pygopagi. Thus there are the two sisters in an old Samoan tale already quoted by me in my paper on "Duplicate Twins, etc."; there is also a Sioux legend of a double woman, cited by Dorsey in *Ann. Rep. Bureau Eth.*, Vol. 11, 1889–1890, p. 480, with a native drawing.

This exhausts the list, so far as known to the writer, excepting fetuses in museum collections. Any additions to this list would be gladly received. It has been frequently observed, by the writer and others, that double twins, and probably separate duplicates, are female in the great majority of cases. This seems well borne out by the above list.

away from the middle line upon either side, so that the two median bilateral planes form an angle of 90° with each other. In accordance with the method employed in former papers, the individual which is on the left hand of the observer, when he con-

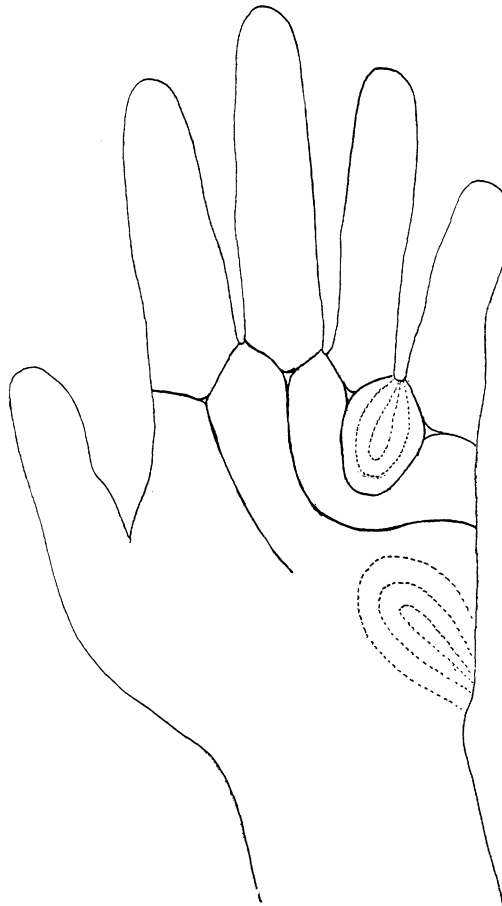


FIG. 26. General pattern for all four hands of the pygopagous twins G———. This was sketched from the rather unsatisfactory studies made upon the active hands of infants of two years. All four hands were of this type.

fronts them, is designated as *A*; the other, upon his right hand, *B*. In this case *Mary* is *A*, and *Margaret* is *B*.

I studied the palms and soles of these little girls in May, 1914, within a few days of their second birthday. They were large and well-developed children, but had not yet learned to walk,

since in attempting it, they would naturally start in nearly opposite directions. They were sitting in a double high chair with a platform in front of them, and appeared almost like two ordinary children, sitting very near together.

I succeeded in taking fairly good prints of their soles, by inking the feet themselves, and then applying quickly a paper pad held flat in the hand, and in this manipulation I was aided by the platform in front of them, which prevented their seeing just what was going on. Prints of the palms, however, in the case of these lively and psychologically alert infants, did not seem feasible, as their hands and fingers were in continual action, and as they were not old enough to have the matter explained to them. The

FIG. 27. Print of left sole of Margaret (Component *A*).

hands were therefore studied as we best could, by the aid of a lens, while the children were being otherwise entertained, and certain of the more conspicuous details were made out. If the children live, as is altogether likely, we may hope for actual prints in three or four years.

Concerning the palms it was fairly definitely made out that

all four are practically alike, and that they conform in both particulars given above to the condition found normal in twins of the duplicate type. In each of the four there is a conspicuous hypothenar loop opening to the ulnar margin, and in each there is also a large loop covering the fourth interdigital area, and opening up between the ring- and little-fingers. Judging from these data the hand pattern for all four hands cannot be very different from the sketch here submitted, with lines *C* and *D* confluent, and with line *B* reaching the margin above (distal to) the hypothenar pattern. (Fig. 26.) Line *A* must be left uncertain, as it can perfectly well

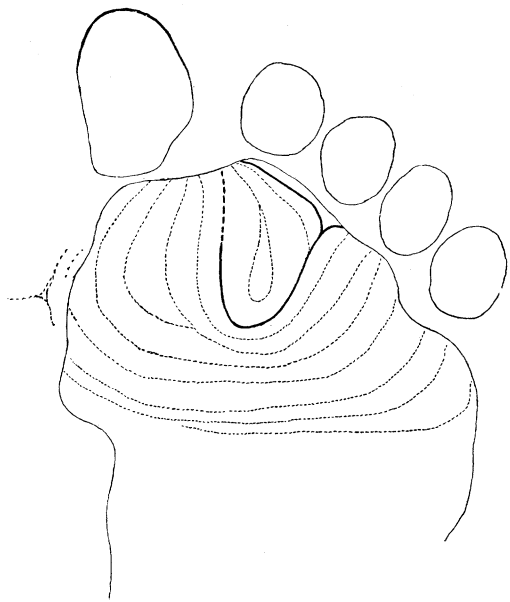


FIG. 28. Print of right sole of Margaret (Component *A*).

follow parallel to *B*, enter the pattern and become involved in it, or emerge below it, that is, assume positions 5, 4, or 3. This will give the formula $8 \cdot 6 \cdot 5 \cdot 5$, with a possible variation in the last term. The correctness of this surmise can be readily tested as soon as the little girls are old enough to assist in the printing.

The prints of the feet, taken as they were, were necessarily poor, but enlarged photographs of the results obtained brought out all the essential details, and it is from these that the outlines here given were taken. As the photographs were taken by a

scientific photographer, and as distortion was avoided, these outlines may be absolutely trusted. The only improvements that better prints could show would be in the details of individual ridges, and other matters which, even in duplicate twins, are individual, and without significance here.

From a comparison of these four outlines (Figs. 27–30) it will be seen at once that here is presented the unexpected; that while three of the four feet, as well as all four hands (presumably) conform

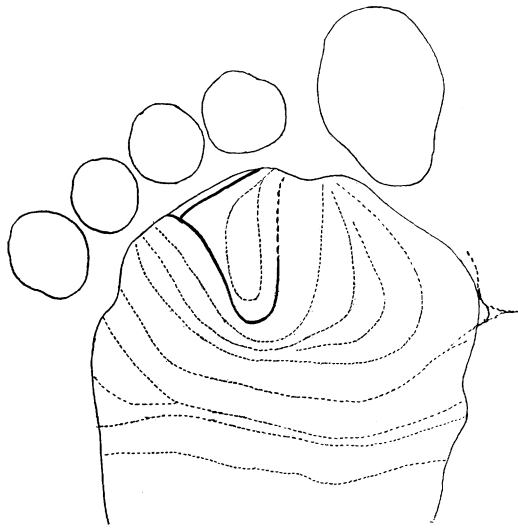


FIG. 29. Print of left sole of Mary (Component *B*).

closely to the requirements for typical duplicates, and that in three of the feet even the curious reduced hallucal pattern, an extremely rare type, is faithfully reproduced, yet in the fourth, the right sole of Mary, there is a radical departure from this type, and a loop of the "A" type is presented instead, *i. e.*, a loop opening up between the first and second toes. Furthermore, there is also in the same print, but not in the others, a well-developed fourth interdigital pattern, lying between the fourth and fifth toes; the presence of two lower triradii, quite absent in the other three soles, are also to be detected.

Taking up these two differences in order, the hallucal pattern of the three feet which are alike is of the extremely rare type *AC*, in which the two triradii *a* and *c* of the typical whorl are absent,

and the ridges consequently escape in both directions through the points naturally held by *a* and *c*, that is, distally between the great toe and the second, and proximo-laterally towards the region of the fourth interdigital area and the outer edge. As shown in the actual prints, or in the tracings from them, here presented, the *b* triradius, which is necessary to the full under-

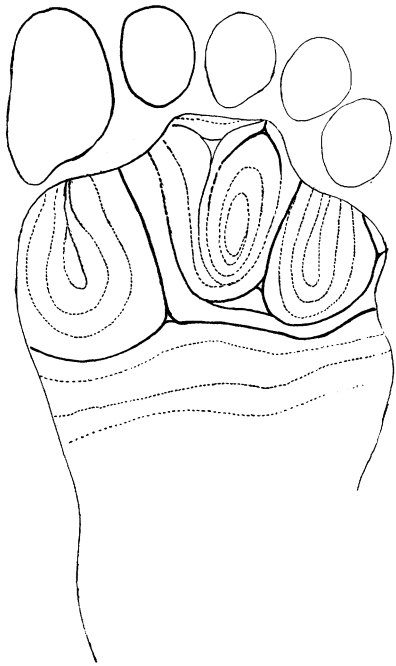


FIG. 30. Print of right sole of Mary (Component *B*).

standing of the relationship, is not shown, but there is no question but what it is present, beyond the tread-area, as indicated by the dotted triradius drawn into each figure.

The difference shown in the aberrant hallucal pattern of Mary's right foot consists in the presence of the *c* triradius, thus closing up all escape for the ridges in that direction, so that consequently they curve around the core and open with the others between the great toe and the next. The essential aberrancy of this pattern consists thus in the presence of a triradius absent in the other cases.

The other difference in this aberrant foot, that affecting the

third interdigital pattern, is also due to the presence of a "lower triradius" between the third and fourth interdigital areas, thus rounding the proximal ridges of both into loops. The two proximal triradii shown in the print may be on the other feet as well, placed beyond the limit of the actual print, and of this explanation for the outer one, *D*, we can be certain, as it is never wanting, but occasionally beyond the limit of the tread-area. The other, closing the third area distally, looks like a departure from the other three soles, thus making the total aberrancy of this foot due to the presence of three separate triradii, which are wanting in the other three.

Summarizing the results of this investigation we have, in all four hands, and in three of the feet, the typical correspondences found only in true duplicates, also the right and left correspondence usual in such cases. That these two individuals are really duplicates there is no possibility of doubt since, in addition to the close facial resemblance, which is typical, and the sex, which is female, the commoner sex for duplicates, they were monochorial and had a double, bilobed placenta. As I was fortunate enough to be on the spot at the time of the birth, I secured the afterbirth, which had been preserved with great care by the attending physicians. There was a single chorion, without trace of a separating partition, and the placenta was bilobed, and nearly as large as two normal placentæ. The umbilical cord was a single one for 11 cm. from the placenta, and proceeded from the margin, at the point of bilobing, that is, at the notch between the two halves.

This common cord contained the usual two arteries and a single median vein, and at the forking of the cord to supply the two umbilici the vein split into two branches, so that one of the arteries and one branch of the vein continued into each individual cord. The cord supplying Margaret, now and always the heavier infant, was 11 cm. long from the fork to the ligature; that supplying Mary was 6. Margaret's cord was also somewhat greater in caliber. Assuming that the ligatures were made in both cases at about the same point these latter figures have a meaning, otherwise they are of little value.

We have thus a conjoined pair of true duplicate twins, monochorial, monosexual, and with striking facial similarity. The

four hands and three of the feet correspond as closely, as has been found in other cases of separate duplicates; but one of the feet shows a series of departures from the type, all due to the presence, or retention, of triradii lost in the other cases. Once or twice in my other sets of apparently duplicate twins I have found about the same degree of difference in one of the members, which has caused me some doubts, and has weakened the argument in the judgment of others, notably Newman and Patterson, 1911, pp. 856–860.

In this case, however, we have twins who are undoubtedly duplicates, and in which the variation is marked in one member of the eight involved, the others showing the typical correspondence in comparing both the two individuals, and the two sides of the same individual. The case is thus of great service in showing the limit of hereditary control affecting a case where the individual differences are expressed as varying degrees of degeneracy or loss of the features of a complex ancestral configuration.

After the presentation of this new piece of evidence on the subject of palm and sole correspondences in duplicate twins, it would seem a fitting time to review briefly the question of the origin of such cases, especially since a flood of light has been shed upon the whole subject by the investigations of Newman and Patterson on the armadillo.

The early stages of normal human individuals during the time in which we are to expect to find the initial stages of the doubling process are practically unknown, and it would be an almost inconceivable chance which would furnish the material for the study of these stages in human eggs destined to produce twins. We have long been wont, however, to rely in such cases upon the analogies furnished by related mammals, and to fill in the breaks in our knowledge by investigation of material taken from other forms. In this way the normal embryology of single human embryos has been well made out, and in a way that is generally accepted, although actual human material, covering important periods of development, is thus far wanting.

In the armadillo the egg is normally polyembryonic, always producing monosexual individuals which, by the number and arrangement of their scales, prove themselves to be duplicates.

In this animal the early stages are now quite fully known, excepting cleavage, and the first visible signs of multiple individuals are here seen in a process of budding of the embryonal anlage. Almost spontaneously comes the impulse to attribute the origin of human twins and other multiple births to a like process, as was done by Patterson at the time of his discovery; writing: "I am therefore bold enough to suggest that the conclusions which I have drawn concerning the origin of the embryos in this mammal may also apply to cases of duplicate twins and double monsters in the human species." To render this still more plausible he then refers to certain similarities in the early embryology of the two animals considered, man and the armadillo, particularly as shown in the Bryce and Teacher embryo, 1908, a similarity which renders this process in man mechanically possible.

Although this conclusion may seem at first to place the origin of these multiple individuals at the time the budding process is first manifest, there is still much evidence to show that this process rests upon an earlier process which conditions it, that is, that *while the visible process of budding first reveals the multiplicity of individuals developing from the egg, the true cause is to be sought further back*, or, as Newman and Patterson, as well as myself, stated at the beginning of our investigation, in some sort of divison (or we may now say, differentiation) of the early blastomeres.

It is now clearly evident that all ideas of an actual physical separation of these blastomeres, a definite *blastotomy*, does not take place, yet many things still point to the conclusion that a similar condition is obtained through some form of differentiation, and that each of the separate embryonal anlages, be they two or four or eight or eleven (a possible number in *Tatusia hybrida*), is the lineal descendant of a single blastomere, formed during early cleavage. This was the view of Newman and Patterson in 1910, who then wrote: "It seems highly probable that the tissues involved in each of the four quadrants of an embryonic vesicle do really arise as the lineal descendants of one of the first four blastomeres." They further believed, as they definitely expressed farther on, that this differentiation was not a blastot-

omy in the sense of anything involving a separation, and supposed that even if an embryo were found in the 4-cell stage, it would present to the eye no differences from that of any other mammalian embryo of four cells. The exact truth of this supposition can be known only by a thorough knowledge of the cell-lineage, from the fertilized egg up to the beginning of the budding process, and although such a task is well-nigh inconceivable with our present technique, the results already obtained render even this possible in the future, perhaps by a culture of eggs outside of the body of the mother.

In 1913, after his important studies of the early embryology of the armadillo, Patterson seems to diverge a little from this view of so early a differentiation, and seems almost to confuse this with blastotomy, or at least to feel that blastotomy is necessarily involved in the process, for he says: "The evidence that has been presented in the first part of this paper [describing the budding process] makes it certain that polyembryonic development in the armadillo cannot be explained on the basis of a spontaneous blastotomy, *in the sense that each embryo is the lineal descendant of a single blastomere of the four-celled stage*, and it causes me to view with some doubt the conclusions of this same nature that have been drawn by those who have worked on other polyembryonic forms." The italics are my own, as I wish to call attention to what seems to be his interpretation of blastotomy, whereas the two things, (1) a separation of the blastomeres, and (2) a line of cell lineage which causes the separate anlages to develop each as the descendant of one of them, are not at all the same, and have no necessary connection. The passage is a little obscure, and the author may not mean to express my interpretation, but it certainly seems as though he has abandoned any connection between the numerous embryos and the first four cells, and considers that the separate individuality commences with the budding process very much later. Whatever may be this author's opinion on this subject, which is very likely not as inferred from this sentence, it would seem to me impossible to get such a close correspondence as has been shown in the armadillo, and in human twins, without starting the separation of identities before there has been any appreciable differentiation in the material that

controls the development and eventual arrangement of the parts in question, and I am of the opinion that a carefully established cell lineage would substantiate the claims of the two authors in 1910, quoted above, or their statement of 1909, "In the case of *Dasypus* [*Tatusia*] each embryo probably arises from one of the blastomeres of the four-celled stage," which does not open the question of whether these blastomeres were actually separated from one another or were only the ancestors of the separate embryonal anlages of a later time. Concerning the blastotomy theory, that is, an actual separation of the blastomeres, I may take this occasion to state that I no longer believe it, since, among other reasons, comes the very cogent one that such a separation in man, or in any mammal, would necessarily produce as many separate and distinct choria, each with its own attachment to the uterus, a condition which is found in fraternal births, each from a separate egg, but never in true polyembryony. In turning to my earlier work, however, I find this theory stated in unequivocal phrase, as "the total separation of the first two blastomeres of a single egg" (1904, p. 462) and I take this opportunity to recant so far as the "total separation" is concerned, while still adhering to the first two blastomeres as the probable ancestors of the two later embryonal buds respectively.

While engaged in noting changes of opinion, I may say further that the view of a different origin for double monsters with unequal components, autosite and parasite, which I asserted in my paper of 1904, pp. 462–463, I rejected utterly later on, 1908, p. 362, and considered such cases as in origin exactly like other double monsters (including separate twins), and that the deformed condition had been brought about by some accident which deprived one of the components of either its normal amount of nourishment, or prevented a normal growth in some mechanical way. As my first view only has been quoted by Newman and Patterson this seems to be an instance of the very common case in which an error is published much more widely than its later correction. Such modifications, or flat rejections, of former views are naturally incident to all progressive thinking, and in a subject so complex and so vital as the present investigation are inevitable.

Concerning the causes which produce a double monster, that

is, twins which have some postembryonal parts in common, and are consequently joined together, the principle of budding, as seen in the armadillo, furnishes some clues as to the possible mechanism of the process. Even in normal twins certain of the embryonal parts are held in common, as always in the armadillo, but as these common parts are embryonic (trophoblast) and are abandoned at birth, they are not apparent later. In double monsters the common parts include more than trophoblastic material and the components are consequently not liberated by the cutting of the umbilical cord.

In a morphological sense the bands of the armadillo carapace, with their variations, and the friction ridges of human palms and soles are partially or wholly homologous structures, so that their use in determining the degree of similarity of twinned individuals is equally warrantable in both cases, while the results may well be compared. Both deal with epidermic structures, the probable homologs of reptilian scales, placed in rows; in both are observed the similar phenomena of the forking and consequent doubling of the lines thus formed. Even the double scale of the armadillo may have its counterpart in a twin sweat-pore, which indicates the composite nature of the unit to which they belong.

While, however, the study of the armadillo has the great and undeniable advantage of allowing the study of the actual embryonic conditions in each case, there are also certain marked advantages in the study of the human palm and sole configuration as a similar criterion of similarity of individuals, and in following the action of heredity. In the first place there is (1) the far greater complexity of pattern, giving an almost infinite number of points for comparison. Here the fineness of the lines, and their occasional participation in the formation of a complex pattern, allows in number and arrangement, to say nothing of the *minutiæ*, that is, the composition of the individual ridges, a complexity far surpassing anything met with in the carapace of the armadillo, where the details concern only nine rows of scales, with some 50–60 unit scales in a row. Another very important advantage is seen in (2) the fact that the records of human twins may easily be made complete, with prints of both parents, father

as well as mother, and sometimes a second preceding generation, together with collateral lines, as represented by brothers and sisters, aunts and uncles. In the work on the armadillo the mothers only are known, and thus all peculiarities of the offspring not accounted for by the maternal carapace, are, rightly or wrongly, attributed to the unknown father. As a third advantage, (3) largely one of convenience, may be mentioned the ease with which even a very large collection of flat prints may be filed and handled. This is especially noticed when a series of prints are to be compared at one time.

On the other hand, there are numerous marked advantages accruing from the study of the armadillo, so many, in fact, that the work is indispensible in the study of human friction ridges. The way in which the results obtained in this field have supplemented the work on human twins, rendering vaguely expressed ideas definite, and raising hypotheses to the category of what by analogy may be considered facts, has been the subject of the preceding pages.

In their paper on the limits of hereditary control in the armadillo (1911) the two authors often quoted offer two objections to my conclusions of a similar nature, as shown in the friction ridge configuration of human twins. The first, and most valid one, is that "the origin of the two individuals from a single fertilized egg is assumed from the facts of resemblance," while the second is that "the comparison between the twins is made only after years of post-natal life." Owing to the abundantly proven unchangeable nature of human friction ridge configuration the second objection is invalid, so that there is left but the first one which may become expanded into two questions, that the early conditions in the embryonic history of human twins is unknown, and that in individual cases it is not usually possible to find out whether they were monochorial or bichorial.

As explained above, analogy with the very similar early stages in the armadillo shows pretty conclusively that human monochorial twins are due to a genuine polyembryony, while in some cases it *is* possible to obtain the chorionic relations, as in the case of the double monster above treated. After collecting the details of a twin case from any responsible physician the case

need not be watched longer than three or four years to get a set of satisfactory prints. These objections have, however, some validity as applied to my definite claims at the time when I first made them (1902, 1904, 1908), and I am only glad that my hypotheses of that time have been so ably and satisfactorily substantiated by the results of the investigation of the armadillo.

That the formation of multiple embryos in man and the armadillo is due in both cases to a similar cause seems to me undoubted, and was similarly considered by Patterson, who writes (1913, p. 560): "There has been considerable speculation as to how 'indentical twins' and similar types of development have arisen, and I believe that these studies on the development of the armadillo will at least indicate how these phenomena may have come about." He further considers it probable that "specific polyembryony in the Dasypodidæ began by the formation of a set of twins, perhaps at first a sporadic case of gemelliparous development such as probably occurs in the production of duplicate twins in the human species." It is needless to state that I, too, think the same, and because of this belief can go farther and state that whatever is learned in the future concerning the actual causes of polyembryony in the armadillo will solve also the same question concerning the causation of human duplicate twins and double monsters.

To close this subject with a pure speculation, suggested by the work upon the armadillo, Newman and Patterson find (1915) that the quadruplets may be arranged in pairs, I+II, and III +IV, and that the identity of scale configuration is much greater in the two members of a single pair than in members of different pairs. Is it conceivable that human duplicates may bear to each other these two degrees of similarity found here, and that the few cases, like my Nos. VII and XIII, where the palm and sole similarity was not so great as was to have been expected from the facial resemblance and correspondence in sex, may be explained by a relationship such as would be found in the armadillo by comparing II with III, or I with IV? This might involve the early abortion of additional embryos, or might deal with the question of the two *vs.* the four-celled stage, as suggested by Newman and Patterson (1909, p. 186) that "the two in-

individuals derived from one of the blastomeres of the two-cell stage ought to be more nearly similar to each other than to the individuals of the other blastomere." Further investigation in

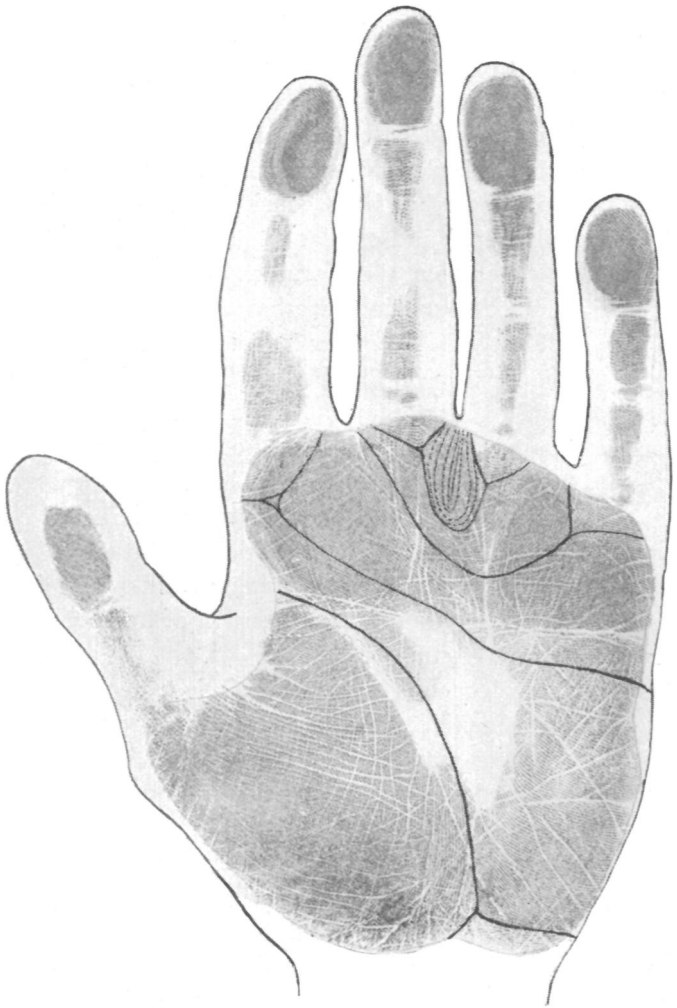


FIG. 31. Print of the right hand of a white male; Coll. No. 96.

the early embryology of the armadillo, particularly the cleavage stages and the cell lineage, are bound to assist in clearing up these problems, and will be awaited with interest.

VI. The Heritability of Friction-Skin Characters.

A casual inspection of the palm and sole prints of any family where two or more generations are represented, and with several children, indicates that the special configuration of the friction-skin ridges is to some extent a character, or series of characters,

Fig. 32. Print of the right hand of the six-year-old son of the foregoing, showing a strong hereditary influence.

transmissible by heredity from parent to offspring. To show this, two pairs of palm prints are here presented, in each case that of a father and son, taken from two unrelated white families.

In the first of these (Figs. 31 and 32) the type presented is no unusual one, yet it is interesting to see how the details of the father are faithfully copied by the smaller hand of the son. The same degree of similarity is shown by the hands of the other side, although the two sides are not alike. Otherwise, so far as may be seen in a boy of six, the son does not especially resemble the father. It is also interesting to note that neither the hands of the mother, nor

of the mother's sister, are in any way like those of the father and son.

The second pair (Figs. 33 and 34) is of still more value as an illustration of direct inheritance, for here the palm of the father presents

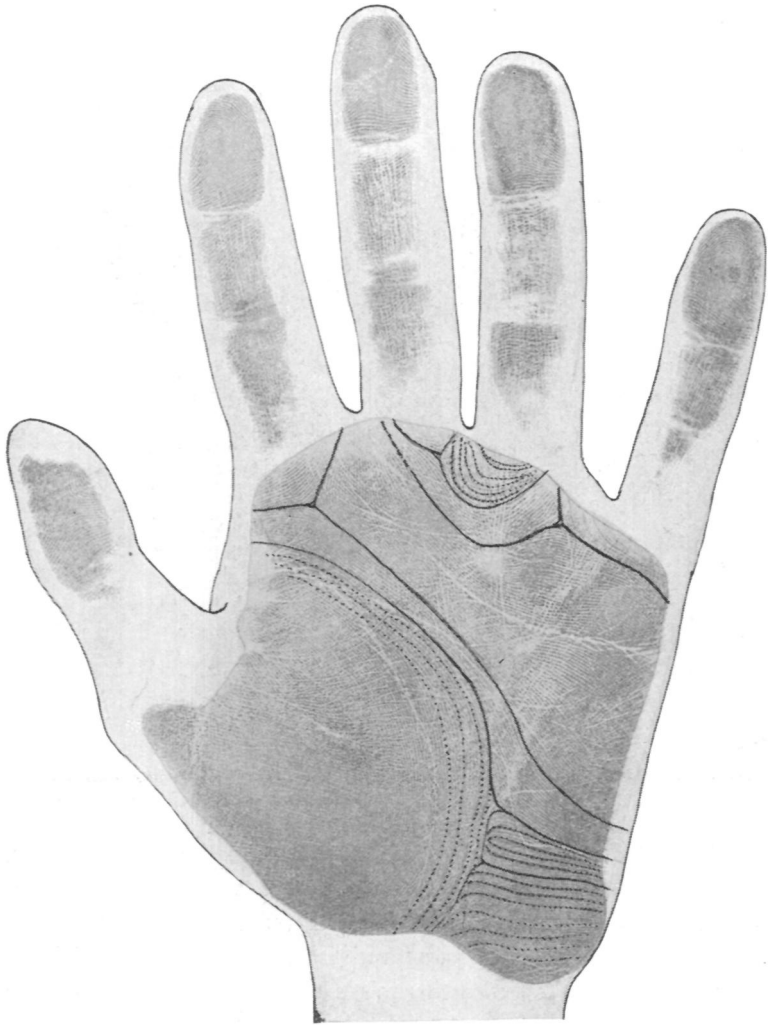


FIG. 33. Print of the right hand of a white male; Coll. No. 99.

two unusual features: (1) the reduction of line *C*, with its triradius, as described above, and (2) the narrowed, and nearly suppressed, hypothenar loop, with two triradii, and with its pattern a loop

opening to the ulnar margin; yet each of these unusual characters is faithfully reproduced in the little hand of his two-year old son. The first of these characters occurs in about 18 per cent. of all cases, although not always to the same degree, as has been stated

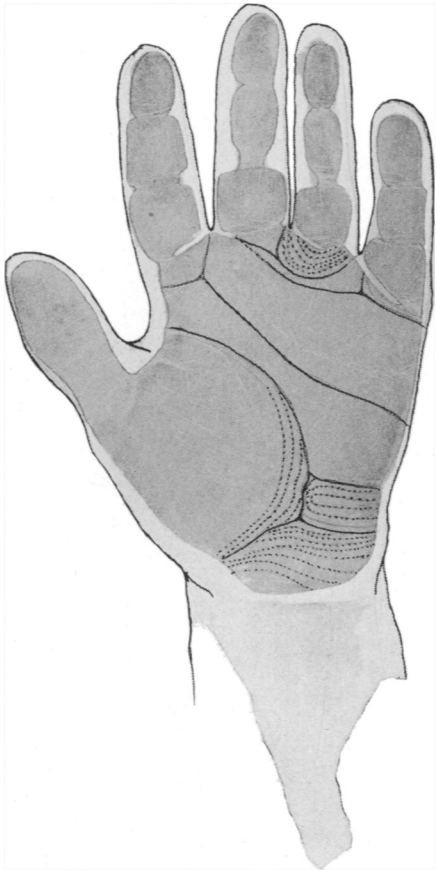


FIG. 34. Print of the two-year-old son of the foregoing, showing a strong hereditary influence, involving in this case two unusual features.

above, but the type of hypothenar here shown is much rarer, and one might have to look over several hundred sets of palm prints before meeting with a similar one. This type is given by Miss Whipple (1904) as *B*, Fig. 47, p. 349, where its development from a more typical pattern is explained. As a test of its frequency of occurrence the hand prints of 100 individuals from my

collection were counted, and in eight hands only was the general type of pattern found, that is, eight out of two hundred, or four per cent., and each of these differed more in the arrangement of

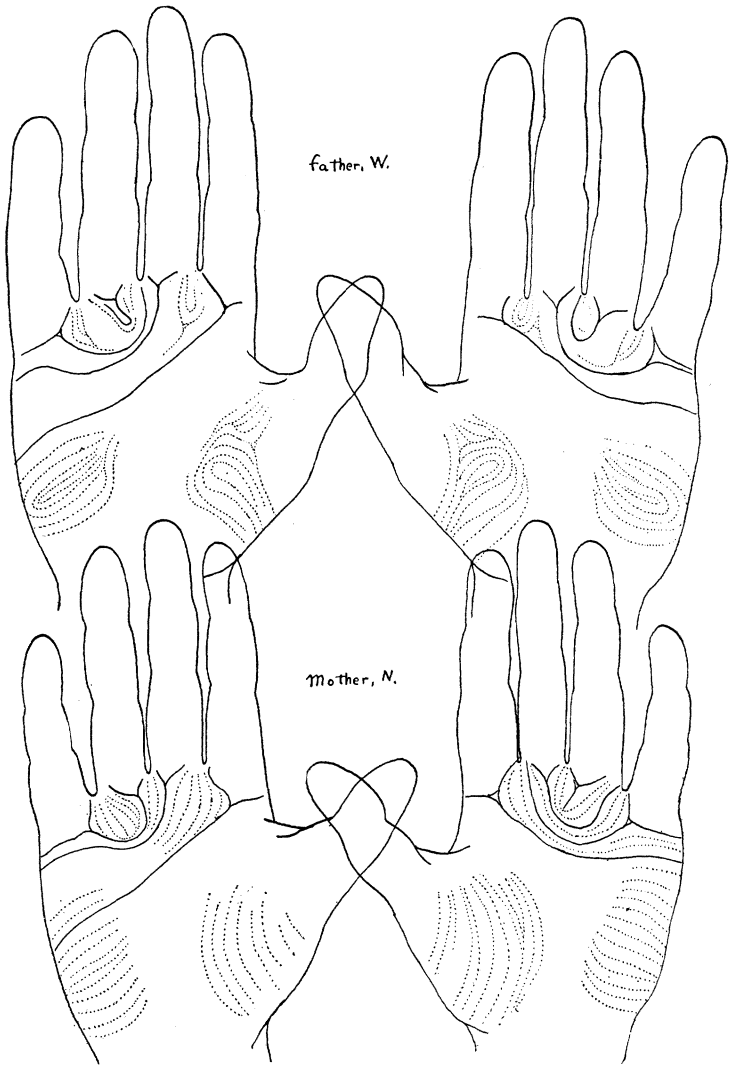


FIG. 35. Tracings of the hand prints of the two parents, *W* and *N*, of the H—— family.

triradii and other details, than do these of father and son. It would be safe to say that the chance of finding two cases with

hypothenar patterns of the same type and with the details so similar would be at most one in a hundred, and probably much less. Multiplying this rough estimate (1 in 100) by the chance of 1 in 12, the figure already obtained for the occurrence of a complete suppression of line *C*, and we get 1 in 1,200 for the probable occurrence of these two characters in combination, relying upon chance alone.

The other hands of this same pair, the lefts, correspond almost as closely, with a like suppression of line *C*, and with the hypothenar in each reduced to a single triradius, and no other trace of a pattern. Here the mother's hands also were both of this latter type with respect to the hypothenar, but the main lines are entirely different.

The results from such isolated instances, however, show merely that *in the friction-skin configuration we are dealing with heritable characters*, and in themselves show little more. A more detailed line of inquiry is offered by the study of a large family, where the parents belong to distinctly different types, and where the children are numerous. Such a family is that of H — from my collection, where the material consists of the complete prints (palms and soles) of the father, *W*, the mother, *N*; and six children, *G*, *V*, *M*, *C*, *F*, and *E*, together with the palm prints of the father's three sisters, *Fa*, *Mi*, and *Lo*, which serve as valuable collateral evidence. Of the six children *F* is a boy, the other five are girls.

The hands of the two parents, *W* and *N*, are of distinctly different types, that of *W*, the father, being very complex, with traces at least of all five palmar patterns, while the palms of the mother, *N*, are unusually free from such special features, and show only an included loop between lines *C* and *D* of the left hand, possibly a fourth interdigital, also a loop across the free end of the rudimentary line *C* of the right, the condition designated in a formula by the digit 8.

These two opposite types, mated, have produced six offspring, in which the presence or absence of the five palmar patterns are presented here in tabular form:

The presence of a pattern is represented by a ×, the absence by —, and a rudiment by r. The two designations in each column

Name.	Thenar.	First Id.	Second Id.	Third Id.	Fourth Id.	Hypoth.
G.....	××	××	− r.	××	−−	−−
V.....	××	−−	−−	××	−−	−−
M.....	×−	−−	−×	××	××	−−
C.....	××	−−	−−	××	r. −	−−
F.....	××	××	××	××	××	−−
E.....	×−	×−	−−	r. ×	×−	r. −

are for the two hands, the designation at the reader's left being the left.

Aside from the various interdigital patterns, which occur in about three fourths of the cases (36 out of 48), and in one case (third) are practically universal, there will be noticed the remarkable result in the case of the two most prominent patterns, *thenar* and *hypothenar;* the former, a somewhat rare pattern, which occurs in only about 4 per cent. of the white race, is present here in 10 out of the 12 hands (83.3 per cent.), while the much commoner hypothenar, occurring in 20 per cent. of hands of the white race, and found also in both hands of the father, is actually present, aside from a rudiment, but once in the 12 (8.3 per cent.). Now as the father has both thenar and hypothenar patterns upon both hands, and as the mother has neither, it would suggest that possibly the thenar region may be here controlled by the male parent, and the hypothenar by the female.

As the thenar pattern is usually so rare, *its almost universal occurrence in this family is without doubt due to direct inheritance from the father.* For more careful examination the cases are here figured. The usual, or typical, thenar pattern is a double one, like that of the father's left, or *G's* left, with two loops turned away from each other, but with the loops themselves in contact. Morphologically the small, upper loop is in reality the first interdigital, while the lower loop is the thenar proper. This family, however, although the typical form is not wanting, shows a strong tendency to suppress the upper, or first interdigital, loop, and in some cases to modify the lower, the course of degeneration following two lines, as follows:

Series 1.—*W*, left, *F*, right; *V*, left, *C*, right.

Series 2.—*W*, left, *M*, left; *V*, right, *E*, left.

Only upon two palms out of the 12, *M*, right and *E*, right, is a pattern entirely lacking in the thenar region.

It thus seems certain, as already said, that there is here an unmistakable case of the inheritance of a thenar pattern from the male parent, and, except for the failure of this in two of the twelve cases, the character acts like a Mendelian dominant. On this basis the failure in these two cases may be explained by (1)

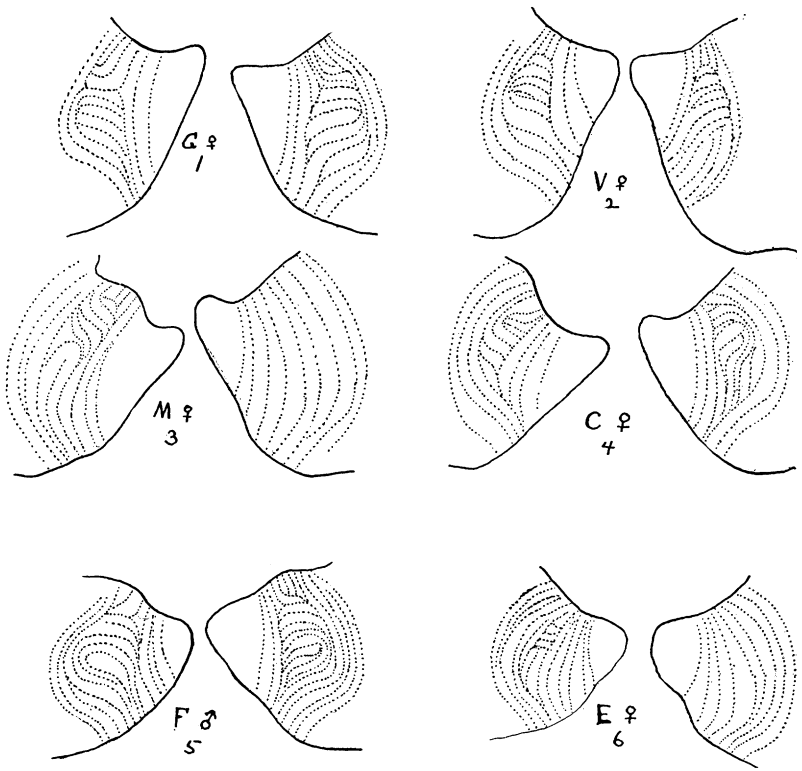


FIG. 36. Tracings of the thenar region in each of the six children of *W* and *N*, the individuals illustrated in the preceding figure. The fifth child, *F*, is a son, the rest daughters.

that the father himself is heterozygous, or (2) that the character is not a unit character. As for the first the collateral evidence of the father's three sisters is to the point, for in these *Fa* and *Mi* have good thenar patterns, on both hands. In the third sister, *Lo*, the extreme smoothness of the skin produced an almost illegible print, although upon the left hand a part of a double pattern, the first interdigital loop, is easily made out, rendering the presence of a thenar figure upon this area absolutely

certain, while it is possible to interpret in a similar way the faint indication of certain lines on the thenar area of the right. It is also noteworthy that the type of pattern upon the right hand of *Fa*, a quite unusual type, is practically identical with that which her niece *C* has upon the same hand. This universality of the thenar pattern in four individuals of the father's generation (8 hands) would suggest dominance.

Concerning the second possibility, that the character here examined, the thenar pattern, is not in itself a Mendelian unit, but is conditioned by two or more factors, this is rendered probable by the many stages of modification, or degeneracy, represented by the hands here represented, eight in the older generation, and ten in the younger. It suggests the presence of a factor tending to reduce the pattern to a series of parallel lines that follow the strong line of flexion bounding the thenar region, the "Line of Life" of the palmist; and the presence of the ancestral thenar pattern, or some stage in its reduction, in so many hands of the H— family, may be due to the absence of this latter factor fully as much as to the presence of a positive thenar pattern unit.

Quite aside from all this, the fact that such grades in the reduction of a pattern may exist, and that for a given pattern there may be found several series of them[1] is in itself a phenomenon of heredity at present inexplicable, for, *while in such a series we may find every step in a definite and continuous process, the steps themselves do not occur in ontogenetic development, but each step arises in an individual embryo precisely in the form which that individual shall retain throughout life.* Since, now, this process of the degeneration of the ridge formation is from a complex pattern to a series of parallel lines; and since the goal sought in this process is in countless details, precisely what would result from the action of external forces upon yielding ridges, as such authors as Miss Whipple and W. Kidd have abundantly shown, we have the startling phenomen of *a Lamarckian environmental influence of a mechanical nature, which, while having no visible effect upon the soma, so modifies the germ-cells that the effect becomes transmitted to the descendants, and that probably by Mendelian methods!* There has thus developed a long series

[1] Cf. Miss Whipple, 1904, pp. 339–352, esp. Fig. 48, p. 350.

of generations, with its beginnings somewhere in the Simian line, the individuals of which, though with many a retrogression, have progressed steadily from a series of complicated patterns, developed in association with raised pad organs, to a simple condition of parallel ridges, more or less conformable to the principal lines of flexure.

Expressed in another way, the results of the study of friction-ridges, especially in connection with their possible heritability, may be collected into a series of definite statements, as follows:

I. Each friction-ridge pattern presents, by taking a large number of human individuals, every stage in the process of development, from a whorl of concentric lines with a definite number of embracing triradii, to a condition in which core and triradii are completely lost and the surface is covered by simple parallel ridges, straight or slightly curved.[1]

II. From comparative study of other Primates it is plain that the course of evolution has been from the involved condition, the whorl, which is distinctly Simian, through every stage in the reduction of the pattern, to its final complete effacement.[2]

III. A given pattern shows as a rule more than one way in which it may degenerate, often two or three, and each way may be shown by complete series of instances taken from individual cases, and leading to the same final result.[3]

IV. The ridges forming a given pattern are first seen in an embryo of approximately four months, since which age there is no indication of change throughout life. This has been absolutely proven in the case of individuals after birth by separate observations taken upon the same person, and in a number of instances these observations have been separated by a period of fifty or more years; in the embryo the ridges appear in a definite form, and there is no indication of later modification or of provision for it.[4]

[1] Miss Whipple, 1904.

[2] Miss Whipple, 1904.

[3] Miss Whipple, 1904, pp. 343–354.

[4] The occurrence of ridge rudiments, occasionally found lying between normal ridges, and reduced often to broken lines without sweat-pores, suggests the possibility that in an early embryonic stage these may have been as large as the others, and that they may have become pushed out of existence, or *suppressed*, owing to some mechanical pressure during ontogeny. Of this we have no proof,

V. It follows, therefore, *that the modifications of the original typical patterns*, as given in II. and III. above, *must be affected through modification of the germ-cells, which determine at each fertilization the form of pattern for the new individual.* These patterns are often atavistic, that is, a primitive pattern may occasionally appear, but in the main the progress has been a decided one, so that the majority of men show a nearly complete effacement of the original complicated condition.

VI. In each given area *the characteristic ridge direction* of a typical human hand *is precisely that to which the ridges would be pushed or pressed if considered plastic and capable of being acted on directly by the objects which naturally come into contact with them in the ordinary uses of the hands and feet.* That is, the ridges are everywhere arranged to run at right angles to the prevailing direction along which contact objects would push or slip. In the hand, which is constantly grasping cylindrical objects, such as boughs, handles of instruments, ropes, and numberless similar things, the ridges of the distal half of the palm tend to lie straight across it, a position which, in the highest degree possible for man, is expressed by the formula 11·9·7·5. It is thus significant that *in the right hands of all human races this formula is found in 22–25 per cent. of the cases*, while in left hands this formula forms only 4 per cent. of the cases.[1] That the same percentages hold among such diverse human races as Whites, Negroes, and Maya Indians marks this as *a natural human tendency, and suggests that this result has been gained since the adoption of right-handedness.*

VII. Finally, (1) since the configuration of the friction-ridges is directly heritable, probably in conformity to the laws of Mendel; (2) since the countless elements involved in the ridge arrangement are precisely similar to what would be produced in

and it is not very likely, yet, until otherwise explained, their occurence prevents the dogmatic assertion that no change can absolutely take place after the ridges are first laid down. Concerning a modification of this sort after birth, this is still less likely, and may be practically denied. The author is in possession of a series of prints of the right forefinger of a child, beginning with the second year, continued at approximately two-year intervals until the age of twelve, and still being collected. In this there is an unusual number of these "suppressed" ridges, yet in the interval covered by the series there has not been the slightest change in any of them.

[1] Wilder, 1904, *Amer. Anthrop.*, Vol. 6, p. 279.

a plastic material by the direct application of the most usual objects, acting in the most usual way, and (3) since no modification of an individual plan of configuration seems possible during ontogeny, or as a result of continued action upon an individual, *we find ourselves confronted by the phenomenon of a complex series of arrangements, each corresponding exactly at all points with the direct result of the action of constantly applied external forces upon plastic structures; and yet, although these external forces are constantly applied, and are without the slightest visible result upon the individual, positive results, cumulative in their effects, are actually transmitted from parent to child. Furthermore, these results must be transmitted by the germ-cells, and are probably in accordance with the Mendelian laws.*

One could hardly find a more startling combination of principles than the above, supporting at the same time the ideas of Lamarck, Mendel, and Weismann, with Darwin left entirely out, since with the reduction in the size of the friction-ridges and the increase in the size of the body, they can be of no real selective value above the Cercopithecidæ; yet from a long and careful study of a large amount of data (perhaps a thousand hand prints, including the most varied human races, studied during fifteen years) every one of the above conclusions seems amply substantiated. The facts stand written upon the palmar and plantar surfaces of mankind; the detailed record of their physical exertions and that of a long line of ancestors; these records are inherited with numerous individual modifications, so that, except in the case of duplicate twins, the offspring of the same two parents are never quite alike; it is easily possible to arrange these individual modifications in developmental series, presumably corresponding to their evolution, and, when so arranged, they follow closely the theoretical series of modifications which would be induced by direct influence from the usual external mechanical forces, in case these structures were sufficiently yielding to allow it.

Such are the conclusions which, from my study of friction-skin configuration, I have reached at present. They seem inevitable, and if so, are exceedingly important; and it is because they seem

so that I wish to make an appeal for others to undertake to investigate the same subject. In the study of friction-skin may be found taxonomy, morphology, ethnology, genetics, as well as the practical application to problems of individual identification. It must be confessed that there is at first a large amount of detail which must be acquired, as well as a certain amount of nomenclature. The bibliography, however, if that which deals with the special work on apical patterns ("finger-prints") be disregarded, is not large, and as it is for the most part recent it can be readily

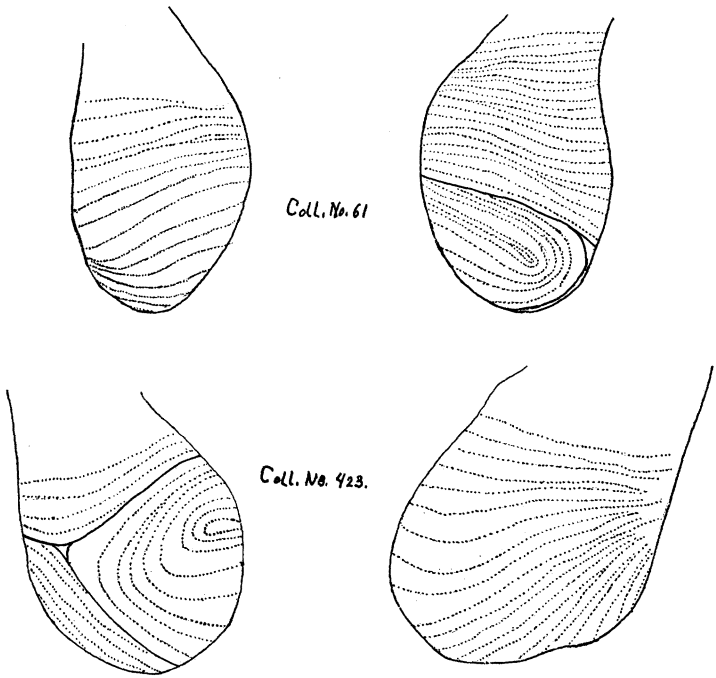


FIG. 37. Tracings of the only calcar patterns in my entire collection, outside of the two families considered below.

obtained. Unlike most biological material, that concerned here is readily obtained, and easily kept, a series of prints being for most purposes more convenient for study than the actual objects; the prints, too, are more accurate records of the facts than are any drawings or even photographs.

We who have been at work along this line are in great need of collaborators. We are firmly impressed with the belief of the

biological importance of the field, and feel that many weighty conclusions are to be drawn from it. It is with the idea of facilitating study that I give here, as the final paper in this series, a bibliography of the subject, which should make the study at once available to those who care to interest themselves in it.

Still more convincing than the inheritance of the thenar pattern in the hands of the H— family is that of the calcar pattern in a family which I may designate as Wh—. This pattern is the rarest of all friction-skin patterns known in man, and has been found once by Schlaginhaufen,[1] once by Féré,[2] and, outside of this family, twice by myself (Fig. 37). In the sole prints of 100 Liberian soldiers, collected by Starr, there is not an instance of it, and Schlaginhaufen states in 1905, including all the observations to date, that it has never been reported in any non-European race.

As it appears upon the tread area this pattern is in the form of a simple loop, with its apex fibulo-proximal and with its opening directed obliquely towards the tibial and distal directions (Fig. 23). This loop is usually accompanied by a triradius placed distally to it and on the fibular side, but this does not always appear upon the tread area, and in general the portion thus included gives the impression of being a part of a more complete figure, the remainder of which should lie farther up on the side of the foot. In fact Schlaginhaufen, who seems to be the only one who has followed this pattern beyond the tread area, has traced the loop in his case over the hollow on the tibial side of the foot and reports that there the lines of the loop converge, turn about, and form a second loop facing the other way and accompanied by a second triradius, so that the entire figure, thus completed, becomes a long drawn out spiral with two loops, one of which lies within the tread area.[3]

Occasionally, though not often, prints are found in which the

[1] 1905; Fig. 178, p. 100.

[2] 1900, Les lignes papillaries de la plante du pied, 1900; Fig. 18, p. 615.

[3] "Ich verfolgte jedoch die Crura des Sinus in tibiodistaler Richtung und gelangte zu folgenden Leistenbild. Gegen die Cavität des Fusses convergieren die Schenkel, um einer über den anderen hinweglaufend umzubiegen; d.h., wir haben eine langgestreckte, linksgewundene Spirale. Ihrem tibiodistalen Ende liegt ein zweiter Triradius an, dessen Lage in die Fusshöhlung fällt." Schlaginhaufen 1905, pp. 100–101.

lines which run across the heel region of the tread area diverge from one another at a point near the tibial margin of the print, or perhaps spread out along this border from a shorter portion of the opposite side, and as this appearance often occurs where there is some connection with a typical calcar pattern (either on the other foot of a subject possessing this pattern or upon those related to such a subject) it gives probability to the surmise that we have here the vestige of a calcar pattern (Fig. 42). If this be so it suggests that the tendency to form a calcar loop is

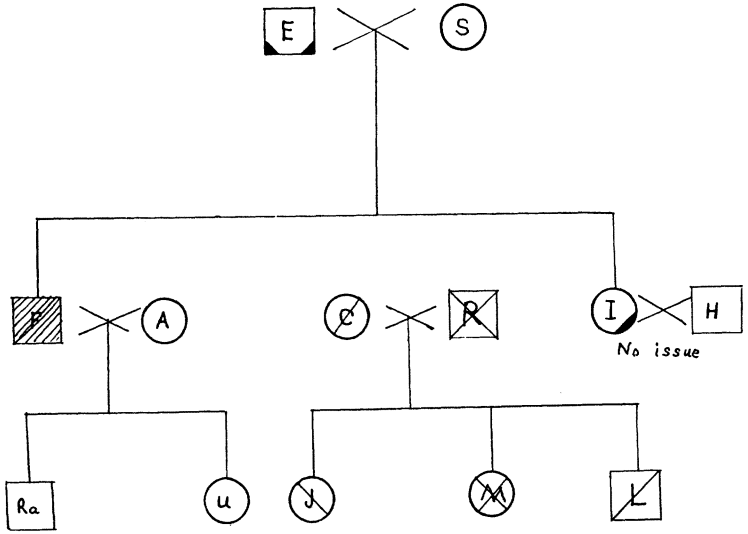


FIG. 38. Diagram of the relationships of family Wh———. The squares represent males, the circles females. A calcar pattern on the right heel is indicated by a diagonal line drawn through the square or circle, from the right above to the left below; one on the left heel by the opposite diagonal. Where both diagonals are used there are two calcar patterns. A divergence, indicating a rudiment of the pattern, is indicated by a black lower corner on the side of the divergence. A shaded square or circle indicates that, through decease or otherwise, prints are not available.

much commoner than the realization, and that a certain configuration, although reduced by some unfavorable influence, is very hard to entirely eradicate.

To proceed now to the conditions obtaining in this family (Wh—). The maternal grandfather *E* and the grandmother *S* show the usual type of heel, save that in the former there is in each foot a noticeable divergence of the lines towards the inner

margin, which although of no especial importance in itself, may in connection with the descendants have some significance. (Fig. 42.)

This pair had one son and two daughters, one of which, the daughter *C*, possesses a calcar loop upon the right heel, and a

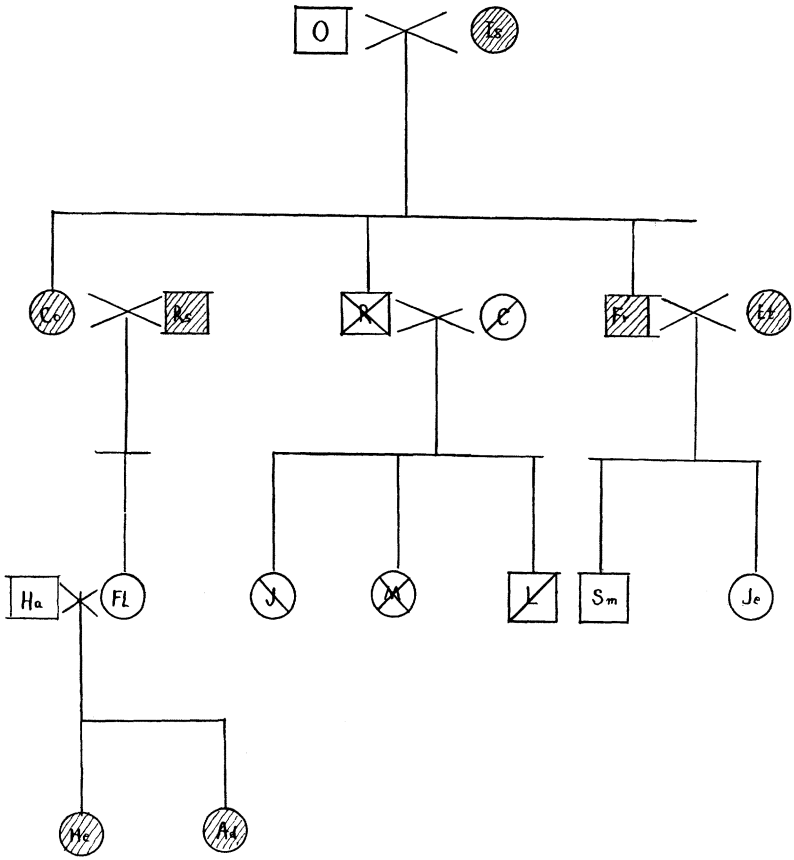


FIG. 39. Diagram of the relationships of the family Wo———, that of the husband, *R*, of the double mating. Symbols as in the previous figure. The sister, *Co*, is deceased, and her husband, *Rs*, is not now available, but their daughter, *Fl*, is normal. Her two children have not yet been investigated. I have not the prints of the brother *Fr*, or of his wife, *Et*, but again the heels of the two children, *Sm* and *Je* are normal. The source of the double calcar pattern of *R* remains thus far unknown.

divergence upon the left. The other daughter, *I*, shows on the right heel a noticeable divergence, but no loop, while the left heel is normal. The son *F* is deceased, but his wife is normal,

and neither of his two children, *Ra* and *U*, show anything unusual in the heel markings.

The daughter C, who possesses one calcar loop, by a most extraordinary coincidence, married an unrelated man, R, who possesses a typical calcar loop on both feet, a case unheard of except in this family, and their three childrem J, M, and L, all possess calcar loops, J (female) upon the left, M (female) upon both, like the father,

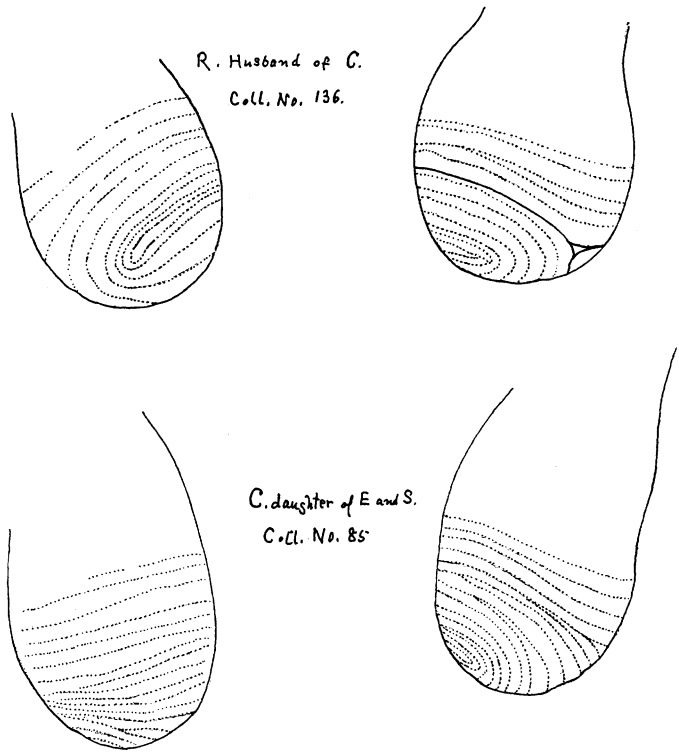
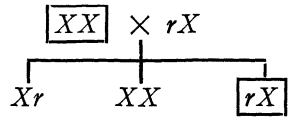


FIG. 40. Tracings of the heel patterns of the mating $R \times C$, the first with double calcar patterns, the second with a single one, the right.

and L (male) upon the right, with a marked divergence on the left. In the right foot of J there is also some divergence. These results may be tabulated as follows, using an *X* for a calcar loop, and an *r* for a divergence. The two symbols used for each individual signify the two feet, in their natural position. The enclosed symbols represent males.



Concerning the source of the calcar loops in the parents, the father of *R* was investigated and found to have quite normal heels; the mother of *C* is also normal, but the father, *E*, shows a good divergence upon both heels. Probably, then, *C* obtained her calcar loop from her father rather than from her mother, and in

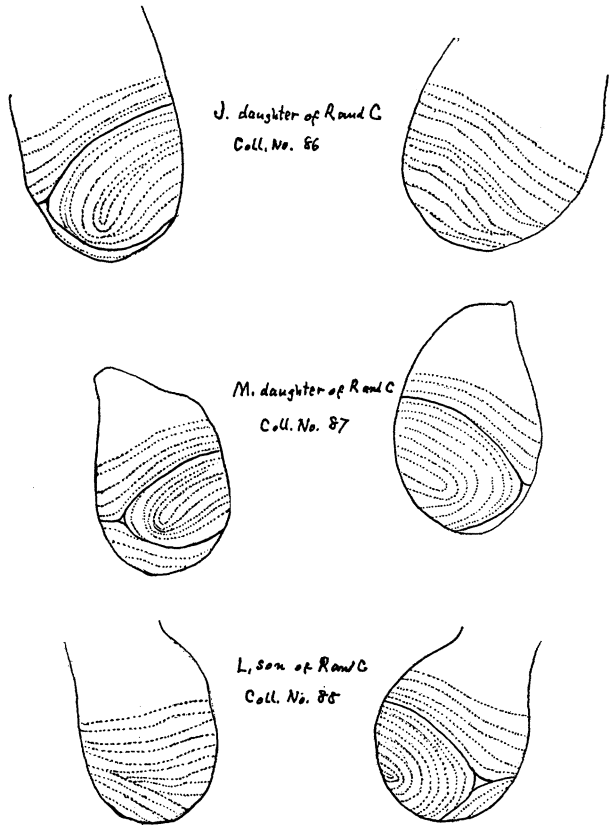


FIG. 41. Heel patterns of the three children of *R* and *C*, shown in the previous figure. The oldest, *J*, has a calcar pattern on the left foot; the second, *M*, on both, and the third, *L*, on the right.

the same way it may be surmised that the husband *R* got his from the side of his deceased mother *Is*, but for lack of further

data this question cannot be definitely decided. Certain brothers and sisters of most of the four grandparents, *E*, *S*, *O*, and *Is*, are still living, but to obtain the necessary data from them would be difficult; there is more to expect from the coming generation, the offspring of *J*, *M*, and *L*, and of their cousins, *Sm* and *Je*, *Ra*, and *U*, but for that several years must elapse.

Leaving the past and the future as open questions, we return

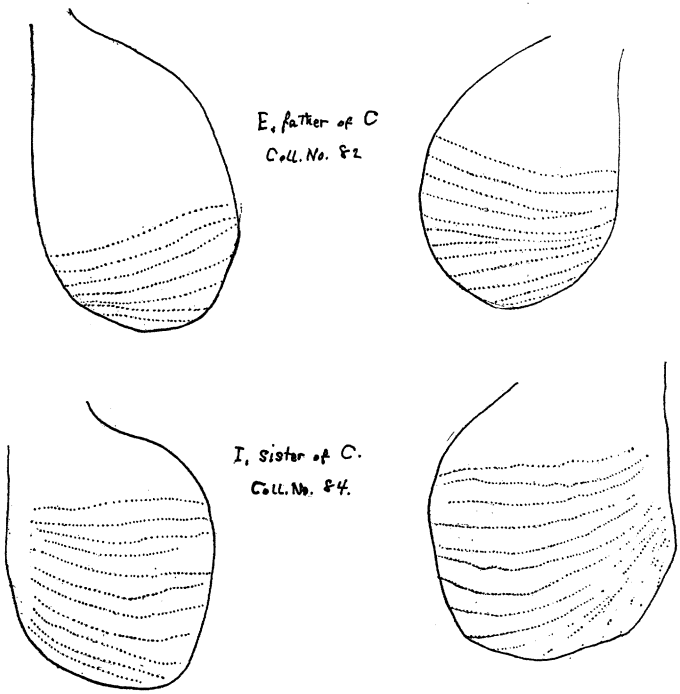


FIG. 42. Heel patterns of the only relatives of *C* which show even a rudiment of a calcar pattern; the father, *E*, and the sister, *I*.

to the facts here presented, and these are, *that a man with a calcar loop on both feet married a woman with a loop and a divergence, and that, of their three children, one has a loop on both feet, and two have a loop on one foot and a divergence on the other, the loop being on the right foot in one case and on the left in the other.* When this record is considered in connection with the fact that, aside from this family, but four loops are known to science (that is, in perhaps 1,000–1,500 individuals of all races) *the direct inheritance of this condition by the mating of* $XX \times rX$ *is beyond question.*

Here there is brought forcibly before the reader the question of *unilateral inheritance*, *i. e.*, whether a character possessed upon the right side only in the parent may cross over in the offspring, and appear on the left side, or whether each side inherits independently. The mother *C* has a loop upon the right foot, and a divergence only upon the left, and the same condition obtains in her son *L*. In the daughter *J*, however, these conditions are reversed, and the right loop in both father and mother fail to govern the right heel of *J*. The loop which *J* possesses upon her left foot may have been inherited from the father, as he has a loop on each foot, but does the loop upon her mother's right foot have any influence? Facts thus far, in all the families studied, tend to show that inheritance does not cross from one side to the other, but we are yet a long way from stating this definitely, or even as a plausible hypothesis. The two definite points that appear as the result of this investigation are (1) *that the calcar loop is heritable, and* (2) *that its presence upon the right foot of both parents does not compel its appearance upon the same foot of the offspring.*

VII. Bibliography of Friction-Skin Configuration.

This list is intended to be complete on the subject of the friction-skin configuration of the palms and soles. On the apical patterns it makes no attempt to be exhaustive, as the subject is now in the hands of the police department of all civilized countries, and has been largely exploited for practical purposes of personal identification, developing a large mass of literature hardly morphological in the technical sense.

There is also little or nothing upon the structure of the skin as such, on its development or histology, or on the innervation, which has been especially a subject of investigation by psychologists.

At the end there is appended a list of the published investigations of Newman and Patterson on the subject of polyembryony in the armadillo, extensively referred to in Section IV. of the present paper. This subject, as it relates to scute and band anomalies of the carapace, and their inheritance by twins and other duplicate individuals, is of special interest here.

D'Abundo.

'91 Contributo allo studio delle impronte digitali. Archivio di Psichiatria. Pisa.

'94 Le impronte digitali in 140 criminali. Riforma medica.

Alix, M.

'67 Recherches sur la disposition des lignes papillaires de la main et du pied. Ann. des Sci. Nat., T. VIII., pp. 295–362.

'69 (Same title.) Ann. des Sci. Nat., T. IX., pp. 5–42.

Bruhns, Fanny.

'10 Der Nagel der Halbaffen und Affen. Morph. Jahrb., Bd. XL., pp. 501–609. (Ridges of finger-tips incidentally mentioned.)

Daae, A.

'94 Ueber Fingerabdrücke und deren Verwendung zur Identitätsfeststellung, verglichen mit Bertillon's Anthropometrischen System (Uebersetzt von Teichmann). Zeitschr. für schweizerisches Strafrecht. Jahrg. VII., p. 317+.

Dixey, F. A. On the Epidermis of the Plantar Surface and the Question of Use-inheritance. Rep. 64th Meeting British Assn. Adv. Sci. (This treats of the thickness of the epidermis on the fetal sole.)

Evatt, E. J.

'06 The Development and Evolution of the " Papillary " Ridges and Patterns on the Volar Surface of the Hand. Journ. Anat. and Physiol., Vol. XLI., pp. 66–71.

Faulds, H.

'80 On the Skin Furrows of the Hand. Letter in Nature, Vol. XXII., p. 605. (This remarkable letter, written from the Tsukiji Hospital, Tokio, anticipates every direction of the later investigation; comp. anat; ethnol; indiv. variations; heredity, etc.)

Faulds, H.

'94 On the Identification of Habitual Criminals by Finger-prints. Nature, Vol. L. (F. claims priority to Sir Wm. Herschel, because of his letter of October 28, 1880, the previous title. Herschel's letter to Nature is dated November 25, 1880.)

Féré, Ch.

(This author has written numerous short papers on the apical patterns of both fingers and toes. The most important citations are the following:)

'91 (Finger and toe patterns.) C. R. soc. biol., Tome 43, pp. 497–506.

'92 (With Batigny, on the same subject.) C. R. soc. biol., Tome 44, pp. 802–806.

'93 (Finger and toe patterns.) Journ. de l'Anat. et de la Physiol. Année, 29, pp. 223–237.

'95 (Sensibility of the balls of the fingers.) C. R. soc. biol., Tome 47, pp. 657–660.

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